Real Time Operation of IEC 61850 Based Digital Substation

Tanuhsree Bhattacharjee, Majid Jamil

Abstract*: *The advancement in technologies applied on substation studies are leading towards substation automation systems (SAS). In SAS network interoperability of substation devices is an important factor that needs good media of communication. IEC 61850 protocol has a greater role in device communications and protection functions of an integrated system. Also this standard can address the problem of interoperability of devices from various vendors. With the implementation of IEC 61850 standards in SAS networks, integration of latest devices like, intelligent electronic devices (IEDs), analog merging units (AMUs) and Ethernet networks are becoming possible. IEC 61850 standards will upgrade a conventional substation model into Digital Substation providing IEDs and modern substation devices are getting installed. In this paper IEC 61850 standard with its various operational levels have been studied for basic understanding of the protocol. A digital substation model with operational architecture has been shown and its various process bus communication messages have been discussed. To establish the concept of interoperability of subsation devices in a substation model, a digital substation laboratory model has been developed here with IEC 61850 standard implementation. Real time analysis of protection functions with process bus communications of the substation model have been executed. The study of IEC 61850 standard and digital substation with its real time hardware test results will give the reader a clear idea about digital substations, substation devices interoperability operations and protection functions. This implementation and application of IEC standards in substation communication and protection functions can get used effectively in future for testing some other network topology.

Keywords* : *Digital substation, IEC 61850 standards, IEDs, Substation automation, Substation protection.

I. INTRODUCTION

Modern power system networks needs good communication media while performing any real time operation. In early ages like 1930's telephonic switching were used for remote control of power units and for monitoring of status of few power network points. After this, digital communications came into role from 1960 onwards. In this system for collection of substation measured data, installation of digital acquisition systems (DAS) were done. The DAS communications were optimized on communication channels with low bandwidth because of bandwidth limitations. This optimization by the protocols was time consuming as it takes time in configuring, mapping and documenting received data locations. Coming to digital age we are having intelligent electronic devices (IEDs) with large numbers of digital and analog data points. Also there are no limits to communication bandwidth. The formation of utility communication architecture (UCA) in 1988 developed the requirement for next generation communication systems. Then forms the IEC TC57 group whose foundation is created by taking concepts and fundamentals of UCA. This group has formulated an international standard IEC 61850 to use in substation communication networks to upgrade it into a digital substation [1].

IEC 61850 forms abstract of data items services and definitions. The mapping of data services and objects to other protocol as per requirement is done with the help of this abstracts. Also substation configuration language (SCL) which is a extensible markup language (XML) based language has been defined in this standard for doing configuration with minimal human error. The IEDs that are enabled with IEC 61850 standard can detect any filed measured input like input of current transformer (CT)/ potential transformer (PT) and it can get automatically assigned to a measurement unit without user intervention. Also most of the substation devices needs to get configured using SCL files, the user need to just import the SCL file to do the configuration. From the devices connected in the network, the IEC 61850 client can get any object definitions. So using this standard any vendor specific devices can get interoperated and also it will save efforts and cost of device configuration [2].

The integrated real time operation of a digital substation as a functional system with standard communication protocol, physical connections, storage share and coordinated control with sequential operation is possible with the model having IEDs, Ethernet based local area network (LAN), IEC 61850 protocol and communication technologies [3].The concept of smart grid also came with the aim of having higher efficiency in every operation and lower outage time by implementing multifunctional IEDs [4].The transfer of time critical messages and security of network has been improved by the use of analog merging units (AMUs) with IEDs operation [5].The IEC standards are having object oriented approach that needs larger data transfer capacity within critical fund investment. The IEC standards are a key component in substation automation system (SAS) network that is used for protection and communication methods of the network with desired performance [6].

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Tanushree Bhattacharjee, Department of Electrical Engineering, Jamia Millia Islamia, New Delhi, India. Email: tanushree18000@gmail.com

Dr. Majid Jamil, Department of Electrical Engineering, Jamia Millia Islamia, New Delhi, India. Email: majidjamil@hotmail.com

IEC 61850 can get implemented in substations with following operations:

- Object model will use to define information form automation functions and primary equipment of plant.
- Abstract will define about substation services, data and data class irrespective of protocol underlying.
- It maps the communication services of IEDs in substation automation system.
- It forms configuration language files for use in substation automation.
- Transfer of system configuration files for configuration of devices at various points of station [7].

II. IEC 61850 STANDARD

To implement any new technology successfully in power system network we need to be able to use legacy IEDs and past protocols with it. IEC 61850 standard has logical devices or LDs to accommodate the past protocols with IEDs. There are complex functions of IEDs that are used to define using simpler functions in IEC 61850 standard and this are called LNs. The logical devices are made from group of LNs and so these are complex functions. IEC standard, models data concentrator by supporting multiple LDs in a single device of station. The IEC 61850 information model for IEDs operation is shown in fig. 1 [8].

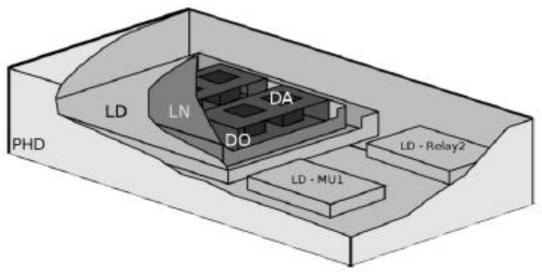

Fig. 1 Information model for IEDs

The communication media used in IEC network can be TCP/IP, Ethernet. The conventional and cost consuming technique of data transfer using copper wires has been replaced by Ethernet networks and it also has improved the communication speed. The devices of IEC 61850 enabled substations are having feature of 'self description' which means it can display its content to client. Overall IEC 61850 standard supports formation of peer to peer communication, client-server communication model and substation configuration [9].

IEC 61850 communication architecture have three operation levels as shown in fig. 2. The levels are defined as per their own specific operations as given below:

Process Level- In this level all the field measuring instruments like CT/PT, sensors, actuators are connected. In this level primary measured values are processed and sent to the bay level through process bus for functioning of IEDs.

Bay Level- In this level all protection and controlling operations of IEDs are performed taking the primary inputs from process bus communication. There are different bays present in a substation model with interconnecting IEDs.

Station Level- In this level all bays data are collected and implementation of functions are also done.This all levels are having data communications between them from both end depending on the system condition [10].

The configuration of IEC 61850 substations are defined with the use of SCL language. Its XML files are having description of different system level with hierarchy of the configuration files [11].

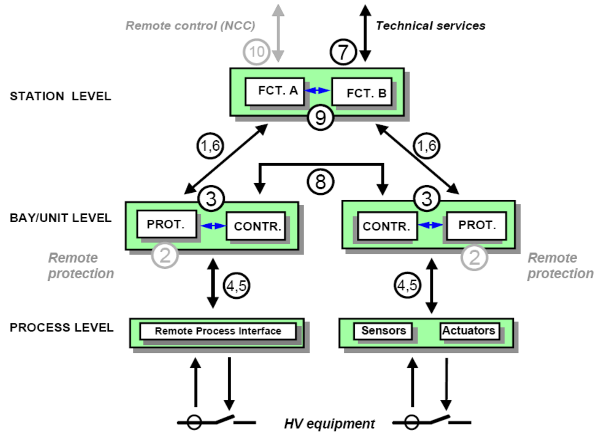

Fig. 2 Different levels of IEC 61850 communication

III. DIGITAL SUBSTATION

A. Substation Model

The IEC 61850 enabled digital substation model with operating architecture is shown in fig. 3. The diagram is showing that the field data gets collected at the process bus level by using CT/PT and sensors. This information will then travel through AMUs that will use to convert this analog information into digital form. The AMUs can be placed in station field site or in a control room. The digital information from the AMU will get transferred to the Ethernet based LAN or WAN communication network. This communication network is used for control and protection operations in primary level communication and called process bus communication. There are also substation level station bus communications and internet based communications to other systems as shown in figure [12].

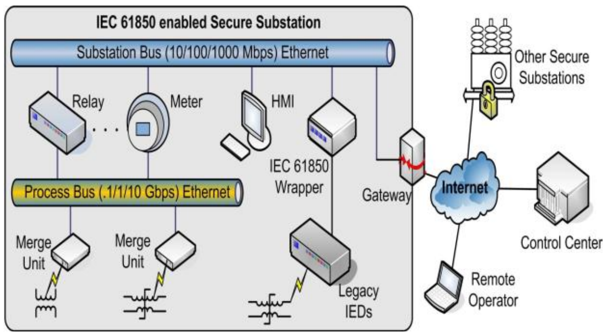

Fig. 3 IEC 61850 based digital substation

Networks with IEC 61850 communication protocol should be so designed that it can support the followings:

1) Communication with client/server architecture
2) Communication with publisher/subscriber architecture
3) Trade-off between delivery reliability and delay
4) Time synchronization
5) Different message types requirement for different quality of service identification [13].

B. Process Bus Communication

The IEC 61850 standard based communication model is having three types of messages: sampled measured values (SMV), generic object oriented substation event (GOOSE) and manufacturing message specification (MMS). The message transfer hierarchies are shown in fig. 4. It can be seen form the figure that MMS transfer is having seven layers stack and GOOSE ,SMV are having three stack message transfer. So, GOOSE and SMV communication is simplified as compared to MMS transfer as these messages are time critical messages. MMS messages are used in station bus level communication while GOOSE and SMV are for process bus communication [14].

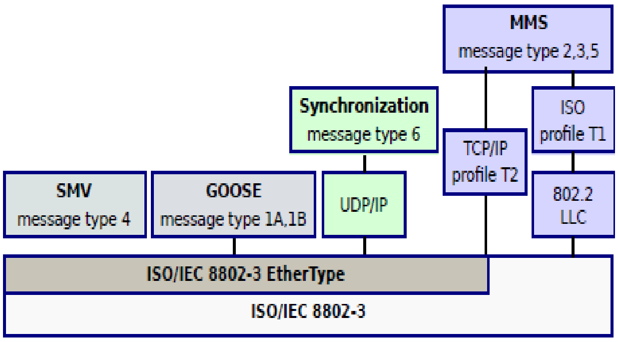

Fig. 4 IEC 61850 process bus communication

IV. DIGITAL SUBSTATION HARDWARE AND RESULT ANALYSIS

A. Hardware set-up

The laboratory set up of digital substation installed with a single line feeder network has been shown in fig. 5.

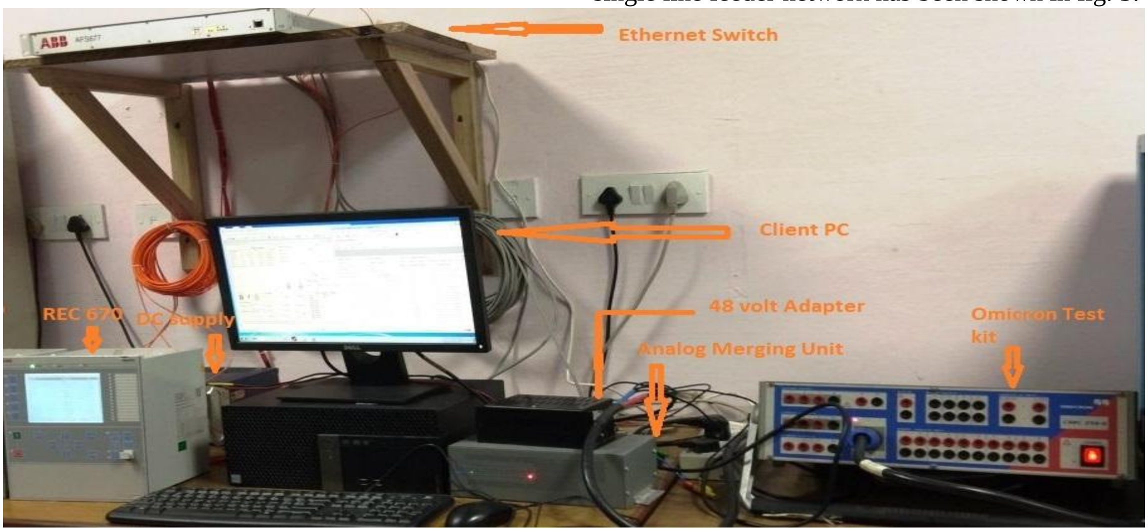

Fig. 5 Digital substation laboratory model

The complete hardware model is having following substation devices and softwares:

- Protection and control IED- REC670
- Analog Merging unit- Vizimax MUG010000
- Ethernet Hub- ABB AFS677
- Test kit- Omicron CMC-256-6
- Personal Computer as client for testing and monitoring
- IED configuration software- PCM600, IED Scoute
- AMU configuration software- Vizimax Commissioning tool
- Test kit configuration software- Omicron Test Universe

The Ethernet switch is connected to IED, AMU, omicron test kit and PC using LAN wires. The digital substation model is enabled with IEC 61850-8-1 protocol which is required for IED to IED or GOOSE communication and IEC 61850-9-2 protocol for SMV communication between test kit and IEDs. The real time analog input signals generated from the Omicron test kit will be considered here as the substation field measured values and then send to the AMU. AMU is used to convert this analog inputs in sampled values or in digital form and through Ethernet LAN network it will travelled to the IED. IED can read this digital signals and will respond as per their configuration.

There are some softwares, needed for operation of this digital substation model. So, the client PC is installed with PCM600 software which is used for configuration of REC670 IED. This software will be also used here for performing all substation operations and monitoring jobs. For configuration of AMU in the network, vizimax commissioning tool is being configured in the PC and for configuration of omicron test kit, test universe software is also installed.

These digital substation model is tested for IEDs protection function operations. To test the model, inputs will get inserted using omicron test kit that is being considered here as the real time field inputs of the station. The test is being performed by taking the substation feeder ratings having voltage 220kV and current 1kA. The omicron kit secondary values which will be the real time inputs to IEDs will have a reduced values of voltage 100V and current 1A because of its secondary turns ratio settings and this set line values will get inserted into the network.

B. Substation testing and result analysis

The REC670 IED is tested here for over voltage protection operation with user defined settings. Here the setting done on IED for over voltage protection is to trip the IED at a over voltage of 120% than the rated voltage taken. In over voltage protection the IED should follow instantaneous curve of relay operation which means that for a fixed set over voltage value the IED should trip at one set point of time. To test the over voltage protection operation, any one line voltage input of the substation can be considered.

Here Line1 or L1 is taken where the test voltage from the omicron will be increased till the IED get tripped automatically keeping other line voltages L2 and L3 constant at 100V line. The real time inputs inserted in the IED from omicron test kit for over voltage protection is shown in fig. 6.

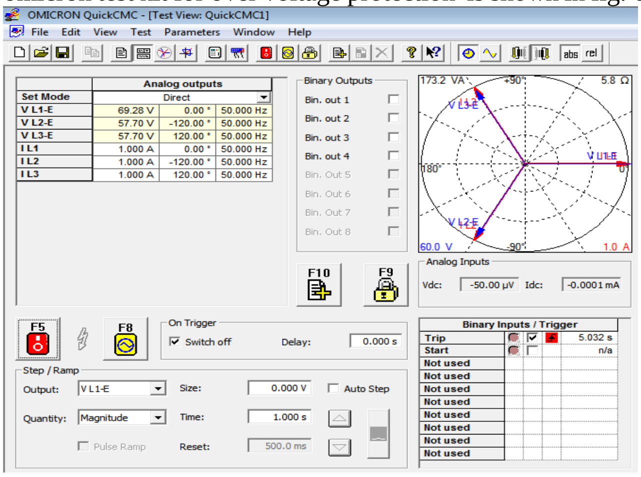

Fig. 6 Real time phase inputs of substation taken from Omicron

From fig. 6 it can be seen that the input current of each line is set at 1A and phase values also remain same as 1A (eq. 4). While the input line voltages are 100V and converting in phase voltage values of 57.7V (eq. 3) for L2 and L3 by applying eq. 1.

$$V_{phase} = V_{line} / \sqrt{3} \tag{1}$$

$$I_{phase} = I_{line} \tag{2}$$

So, from eq. 1 :

$$V_{phase} = 100/\sqrt{3} = 57.7\ V \tag{3}$$

&

$$I_{phase} = I_{line} = 1A \tag{4}$$

Where, $V_{line} = 100\ V$ and $I_{line} = 1A$

Also the phase voltage of L1 is increased to 120% of rated value to test the over voltage protection operation of IED as eq. 5.

$$V_{L1phase} = 1.2 \times 57.7 = 69.2\ V \tag{5}$$

This inputs will be given to the AMU so that it can transform these analog inputs in digital form and transfer this SMV messages to IED. Now the AMU will convert the omicron inputs back to the standard substation ratings considered before by its TRM(Turn ratio meter) settings. So, the ultimate real time inputs that are inserted to the IED from the AMU will have values of 220kV and 1kA. This are SMV messages transferred from the AMU to the REC670 IED through Ethernet LAN network. The test values from the IED with voltage and current waveforms of the over voltage protection test are as shown in fig. 7- 10.

TRM setting of AMU:

CT ratio - 1000:1

PT ratio - 1:2200

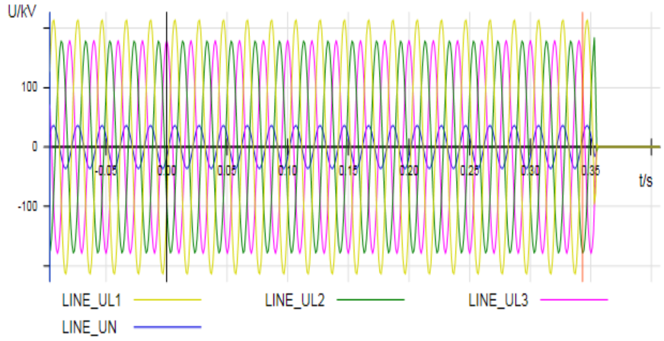

Fig. 7 IED voltage waveform with over voltage in L1

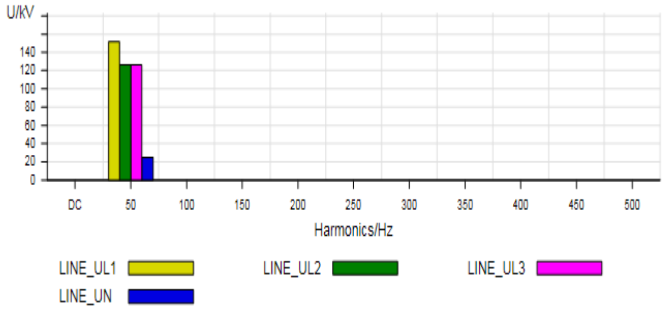

Fig. 8 Three phase voltage values at substation frequency

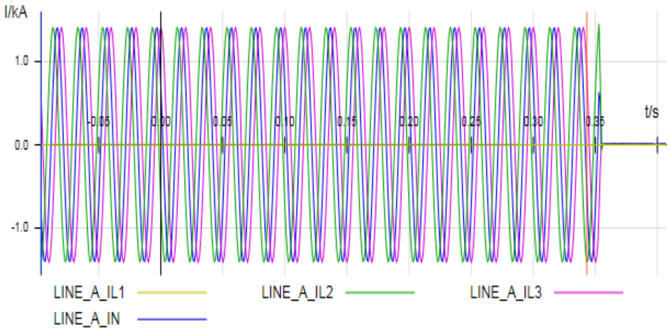

Fig. 9 Three phase currents of substation

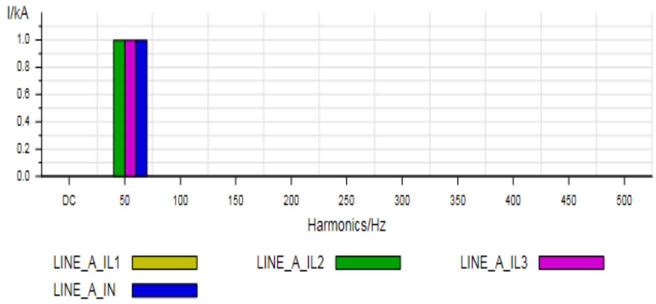

Fig. 10. Three phase current values at substation frequency

From test results it can be seen that the real time substation SMV messages got transferred in the IED correctly.

So, it is being established here that substation process bus communications as SMV messages have been implemented in the digital substation model successfully. The over voltage protection test results as shown in fig. 7 & 8 depicts that the SMV messages voltage output of IED is having phase voltage 127kV in both L2 and L3 lines as given in eq. 6. While L1 line is having 152kV phase voltage as calculated in eq. 7 which is 120% of rated 127kV phase voltage.

Table- I: Over voltage protection test results of IED

Measuring Signal	Value	Phase	Extremum	DC	2.Harmon.	3.Harmon.	5.Harmon.
LINE_A_IL1	0.037 A	-6.7°	1.587 A	4196.4%	47.0%	19.4%	28.3%
LINE_A_IL2	1.00 kA	-149.4°	-1.408 kA	-0.0%	0.0%	0.0%	0.0%
LINE_A_IL3	1.00 kA	90.6°	1.414 kA	0.0%	0.0%	0.0%	0.0%
LINE_A_IN	1.00 kA	150.6°	-1.402 kA	0.2%	0.0%	0.0%	0.0%
LINE_UL1	152 kV	-29.4°	214.0 kV	0.0%	0.0%	0.0%	0.0%
LINE_UL2	127 kV	-149.4°	-178.7 kV	0.0%	0.0%	0.0%	0.0%
LINE_UL3	127 kV	90.6°	179.4 kV	0.0%	0.0%	0.0%	0.0%
LINE_UN	25.6 kV	-29.4°	35.90 kV	0.1%	0.0%	0.0%	0.0%
//LINE M CTN	0.0000	0.0°	0.0000				

If convert this phase voltage values in line voltage then will get 220kV in L2 and L3 line with 264kV in L1 line which were the standard values of the substation taken.. Also the current outputs shown in fig. 9 & 10 states that the IED current is 1kA which was substation rated input.

From eq. 1

$$V_{L2,L3phase} = 220/\sqrt{3} = 127kV \quad (6)$$

$$\& \;\; V_{L1phase} = 1.2 \times 127 = 152kV \quad (7)$$

The test results shows that the IED tripped when the over voltage rating exceeds 120% in line L1 and it tripped in 0.35seconds as per the settings. The test values of IED over voltage protection operation is shown in table 1. From table 1 the voltage and current values in each lines can be seen. Also while performing tripping operation on L1, harmonics contents do present in the line and the percentages are as shown in table.

All above results with real time inputs to the IED verifies that the substation has been successfully implemented and tested with standard result outputs. So, this single line feeder digital substation model can be used with more complex network topology and devices get connected in it for future applications.

V. CONCLUSION

This paper is having discussion on IEC 61850 standard based digital substations and its operations. To address the issues of interoperability operation of substation devices a single line feeder digital substation model laboratory implementation with IEC 61850 standard have been executed and tested for its process bus communications and protection operations of IED. Here Real time omicron test kit inputs have been successfully transferred from AMU to IED as SMV process bus communications via Ethernet LAN network and the IED is being tested with over voltage protection tripping by sending this SMV messages with user defined settings. All the test results are giving standard result outputs that proved the successful implementation of IEC 61850 standards in the digital substation hardware model. With this laboratory model, interopebaility of SAS networks and role of IEC 61850 standards have been established.

As a future work this model can be extended with more devices and a complex LAN network communications with other result outputs.

REFERENCES

1. Baigent, Drew, Mark Adamiak, Ralph Mackiewicz, and GE Multilin GE Multilin SISCO. "IEC 61850 communication networks and systems in substations: An overview for users." *SISCO Systems* (2004).
2. Zhang, Jianqing, and Carl A. Gunter. "Iec 61850-communication networks and systems in substations: an overview of computer science." *University of Illinois at Urbana-Champaign* (2007).
3. Liu, Yunpeng, Hong Wei, Liang Wang, and Tao Zhao. "Ethernet communication based on the IEC61850-line monitoring of electrical equipment IED." *In Condition Monitoring and Diagnosis (CMD), 2012 International Conference on*, pp. 778-781. IEEE, 2012.
4. Apostolov, Alexander, and B. Vandiver. "Methods and tools for functional testing of System Integrity Protection Schemes." (2014): 5-2.
5. Zheng, Yongkang, Mingliang Wu, and Zhiqiang Peng. "A Close-Loop Conformance Testing System of IEC 61850." *Journal of Communications* 11, no. 8 (2016): 779-784.
6. León, Héctor, Carlos Montez, Marcelo Stemmer, and Francisco Vasques. "Simulation models for IEC 61850 communication in electrical substations using GOOSE and SMV time-critical messages." In *WFCS*, pp. 1-8. 2016.
7. Sidhu, Tarlochan S., and Yujie Yin. "Modelling and simulation for performance evaluation of IEC61850-based substation communication systems." *IEEE transactions on power delivery22*, no. 3 (2007): 1482-1489.
8. Pham, Giang T. "Integration of IEC 61850 MMS and LTE to support smart metering communications." *Master's thesis, University of Twente*, 2013.
9. Patil, Mayur, S. R. Bhide, and S. S. Bhat. "Experimenting with IEC 61850 and GOOSE messaging." In *Power, Control & Embedded Systems (ICPCES), 2017 4th International Conference* on, pp. 1-6. IEEE, 2017.
10. Apostolov, Alexander. "Multi-agent systems and IEC 61850." In *2006 IEEE Power Engineering Society General Meeting*, pp. 6-pp. IEEE, 2006.
11. Sidhu, Tarlochan S., Mitalkumar G. Kanabar, and Palak P. Parikh. "Implementation issues with IEC 61850 based substation automation systems." *In Fifteenth National Power Systems Conference*, str, 2008, pp. 473-478.
12. Lei, Hangtian, Chanan Singh, and Alex Sprintson. "Reliability modeling and analysis of IEC 61850 based substation protection systems." *IEEE Transactions on Smart Grid 5*, no. 5 (2014): 2194-2202.

13. Ozansoy, Cagil R., Aladin Zayegh, and Akhtar Kalam. "The real-time publisher/subscriber communication model for distributed substation systems." *IEEE transactions on power delivery 22*, no. 3 (2007): 1411-1423.
14. International Electrotechnical Commission. "IEC TC 57 Power Systems management and associated information exchange." (2011).

AUTHORS PROFILE

Ms. Tanushree bhattacharjee, she has received her M.E. in power system from Indian Institute of Engineering Science and Technology, Shibpur in 2014. In 2009, she has received her B-Tech in Electrical Engineering from Kurukshetra University. Currently, she is pursuing her Ph.D. in Power Systems from Jamia Millia Islamia, New Delhi, India. She has served as a project fellow in UGC SAP DRS-II project at Jamia Millia Islamia, New Delhi. Also She has served as an Asst. Professor at DCE Gurgaon and MNIT Jaipur. She started her career as a lecturer at REMTECH Shamli. She has 2 published papers in her area of research and communicated several others to peer reviewed journals and conferences. Her areas of interest are power systems, substation automation, PV inverters, microgrids and optimization techniques.

Dr Majid Jamil, He obtained his Ph.D. in Power Systems, Electrical Engineering from J.M.I., New Delhi, India, in 2001. He did M.Sc. Engg. from AMU, Aligarh, India in 1992 and B.Sc. Engg. (Electrical Engineering) from Jamia Millia Islamia, New Delhi, India in 1989. He is a Professor and former Head in the Department of Electrical Engineering, Faculty of Engineering & Technology, Jamia Millia Islamia, New Delhi. He has also served as an Asst Professor at BITS Pilani Dubai Campus. He has published more than 130 papers in his area of research. He has published one book Grid Integration of Solar Photovoltaic Systems, CRC Press, (Taylor and Francis Group), 2017, edited 2 books and has written several book chapters. Prof. Jamil is a fellow of Institute of Engineers and IETE, Senior Member IEEE and life member of ISTE, ICTP. His areas of interest are power systems, energy, energy auditing and intelligent techniques.